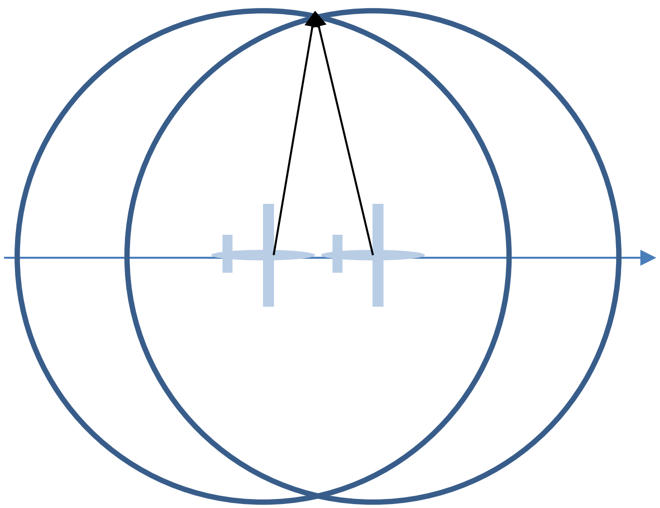
Observing Submesoscale Air-Sea Interaction with Doppler Scatterometry

E. Rodríguez, A. Wineteer, D. Perkovic-Martin
Jet Propulsion Laboratory
California Institute of Technology

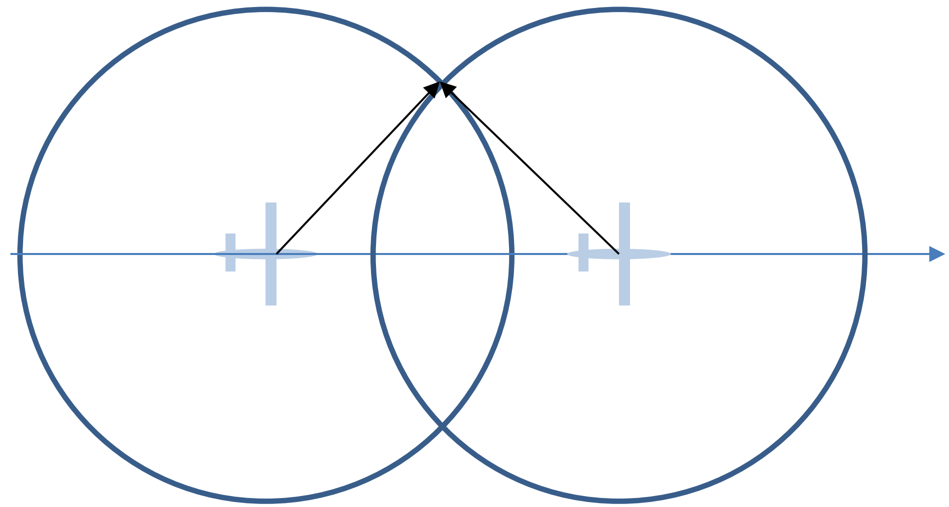
What problem are we trying to solve?

- We want to understand submesoscale to mesoscale circulation and air-sea interaction and build the groundwork for a future spaceborne mission.
- What we need:
  - Synoptic large scale coverage (~200 km x 100 km)
  - Mapping <6 hours
  - Resolution sufficient to resolve submesoscale features (200 m – 400 m)
  - Simultaneous surface currents and winds
  - Ability to compute relative vorticity, divergence, wind stress curl and divergence
  - Ability to operate away from shore
  - Measurements scalable to a spaceborne mission (not same accuracy, but better than daily coverage)

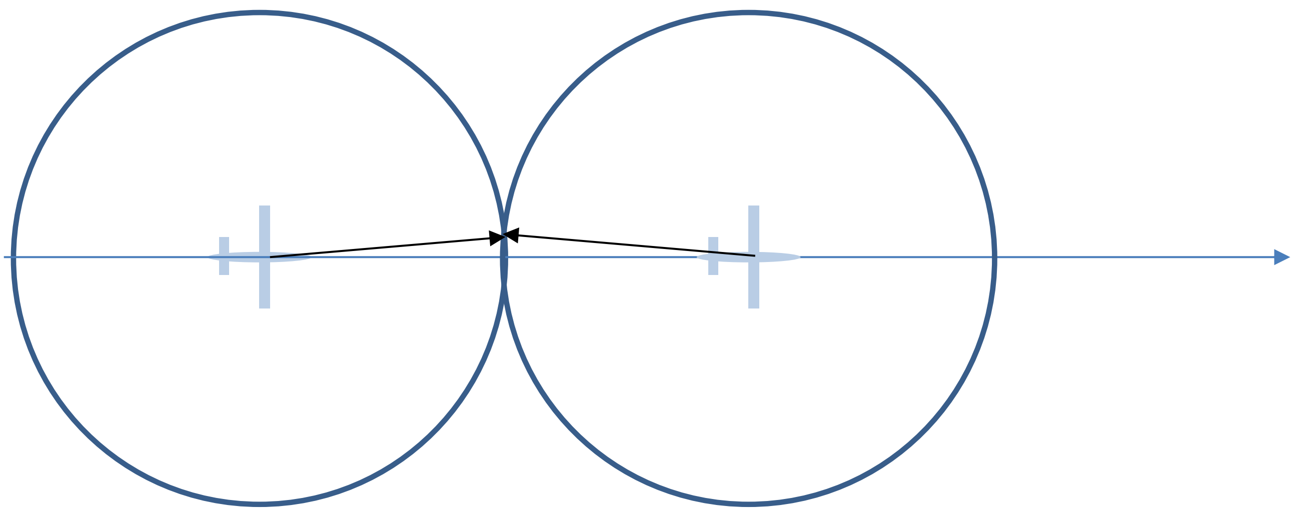
DopplerScatt Vector Estimation



Bad azimuth diversity



Good azimuth diversity



Bad azimuth diversity

DopplerScatt Overview

DopplerScatt Programmtic Overview

Scanning Doppler radar developed under NASA's IIP program

Becoming operational under NASA AITT program by 2019

Data Products:

1.Vector ocean surface currents

2.Vector ocean surface winds

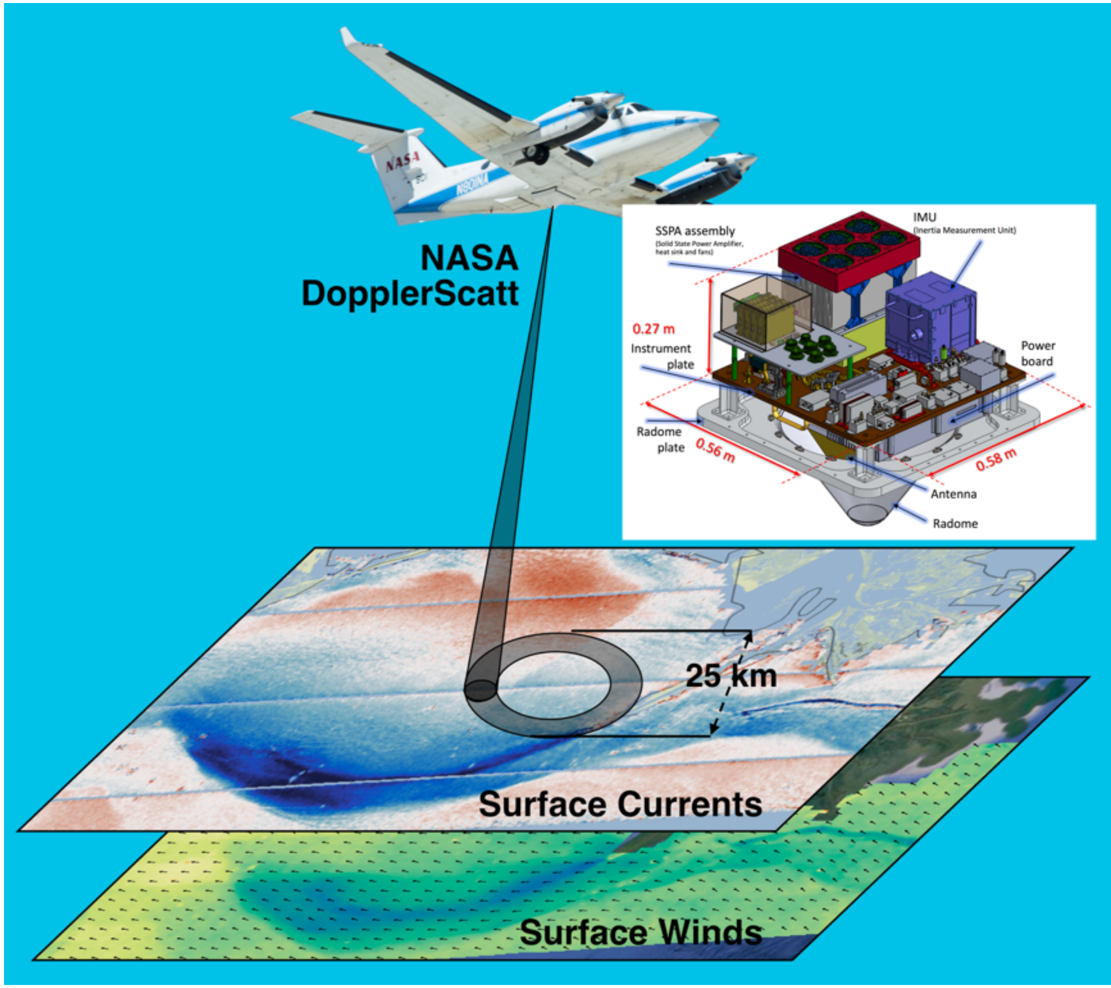
3.Radar brightness maps (sensitive to surfactants such as oil films)).

Mapping capabilities:

- 25 km swath
- maps 200km x 100km area in about 4 hrs
- 200m data product posting
- Mapping within ~600 m of coast
- ~5-10 cm/s radial velocity precision.
- ~ 1 m/s wind speed, <20° wind direction.

Campaigns flown/planned:

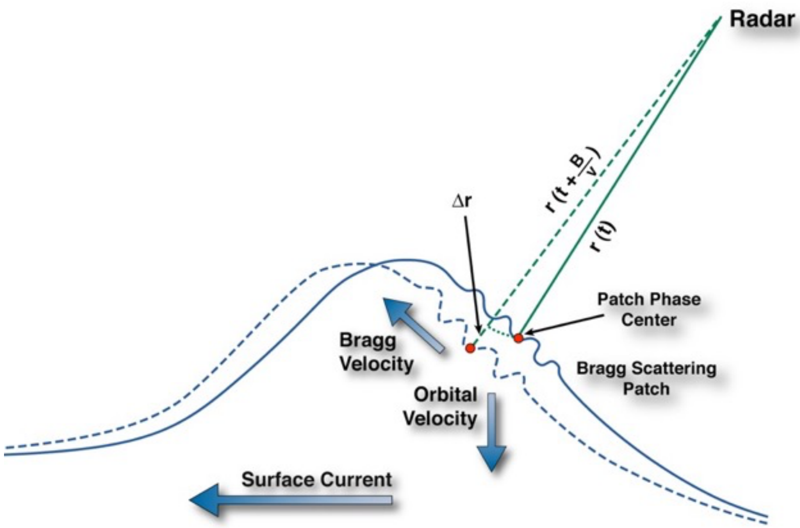
- Oregon coast (2016)
- SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) in Mississippi River Plume
- KISS-CANON in Monterey Bay May 1-4, 2017.
- Chevron GoM (March, 2018)
- California current (August, 2018)



What velocity are we measuring?

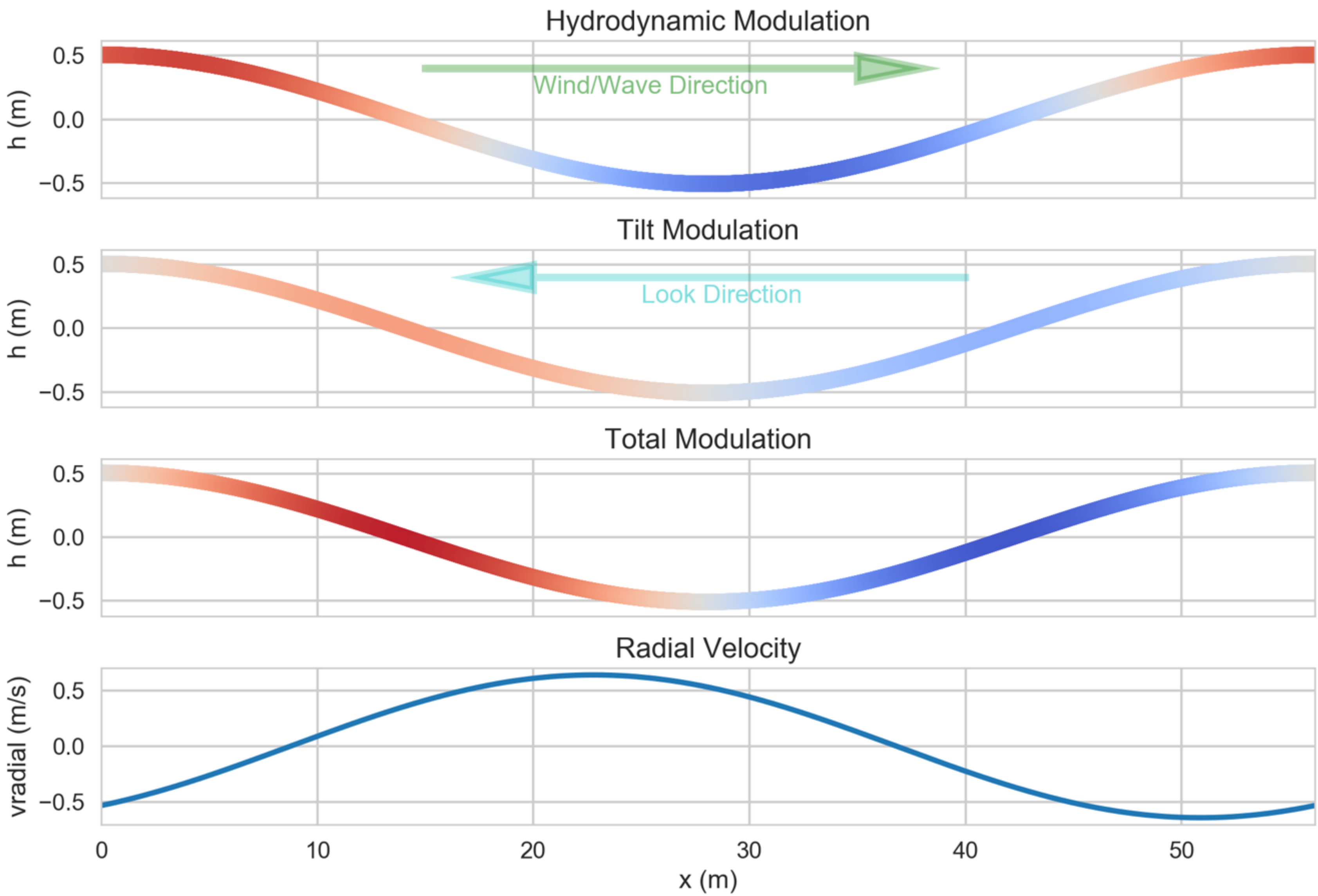
$$\Phi = \frac{2\pi}{\lambda}\Delta r$$

$$v_{scatterer} = \frac{\Delta r}{B} v_{platform}$$

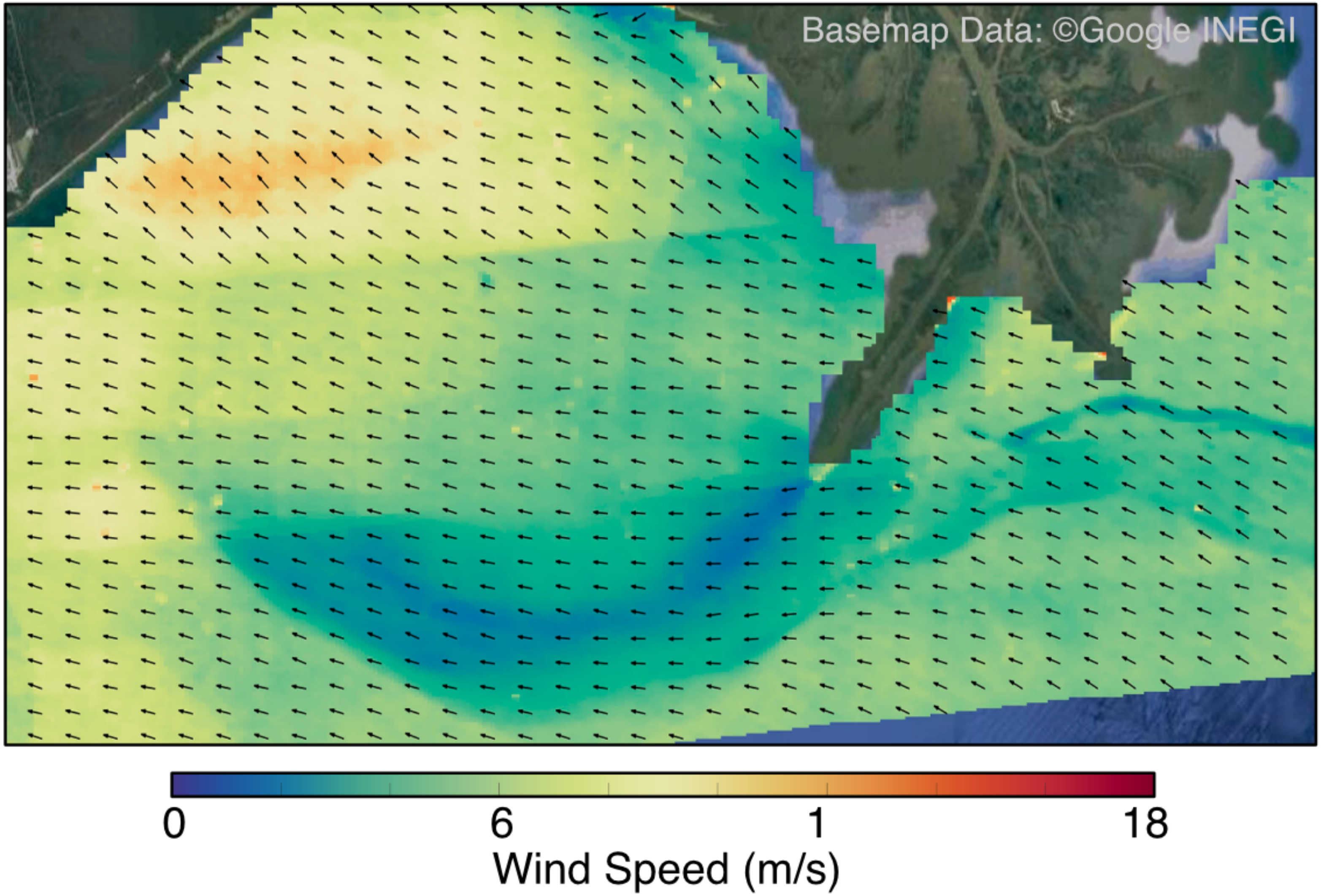


- Radar sensitive to phase speed ~0.5 cm capillary waves (off-nadir) or tilts and small scale slope variations (near nadir)
- Free wave phase speed: ~31 cm/s. Capillary waves can also be generated as bound waves due to straining: will travel at straining wave phase speed (low wind speeds).
- Phase speed modulated by surface currents. Winds will add Stokes drift & surface drift.
- Gravity wave orbital velocity is added to capillary wave velocity. When averaging over surface waves, velocity is weighted (by radar brightness) spatial average.
- Brightness not homogeneous over long wave:
    - Hydrodynamic modulation due to 1) capillary amplitude modulation by spatially varying orbital velocity,; 2) wave breaking; 3) bound waves

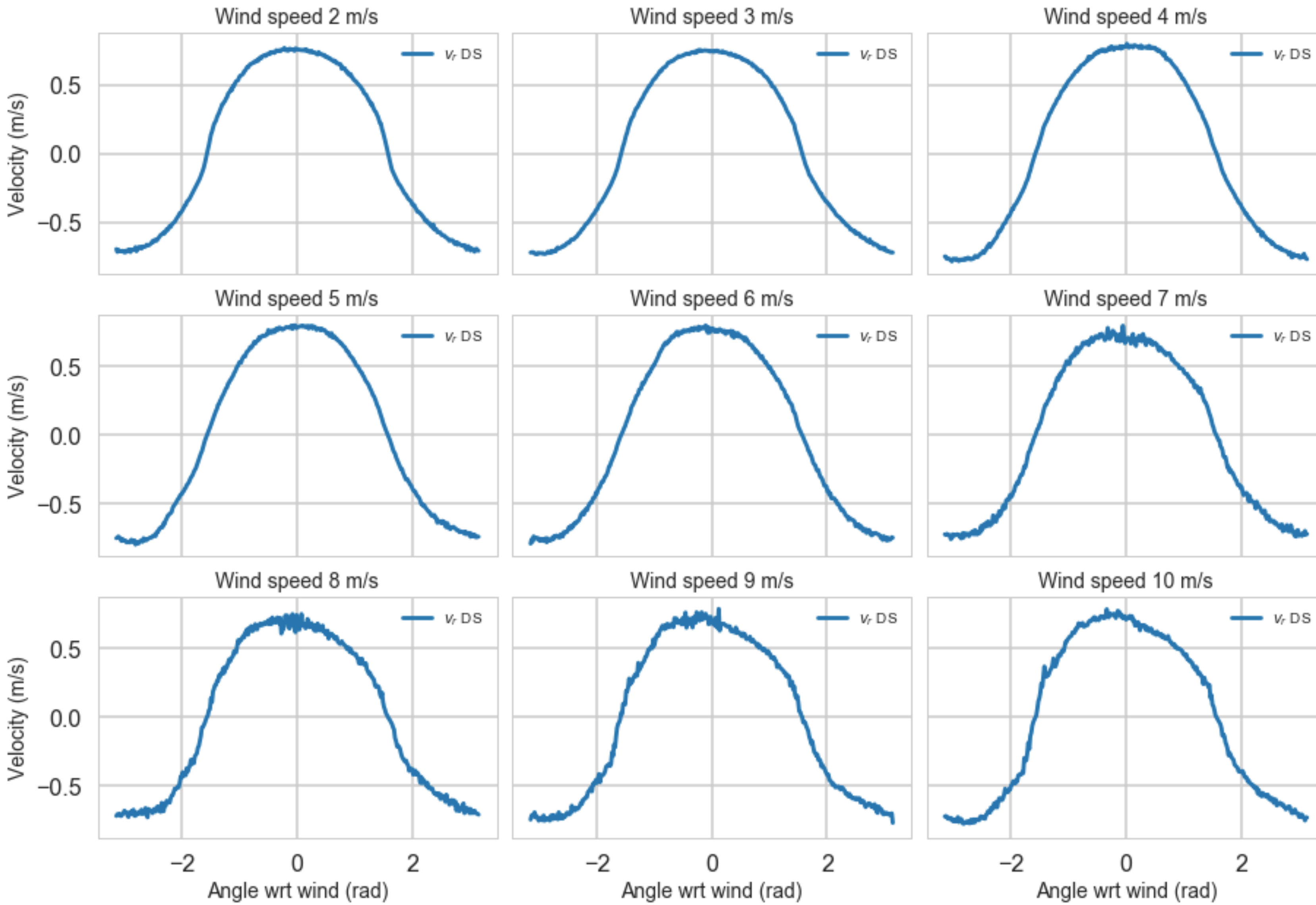
Radar Brightness Modulation



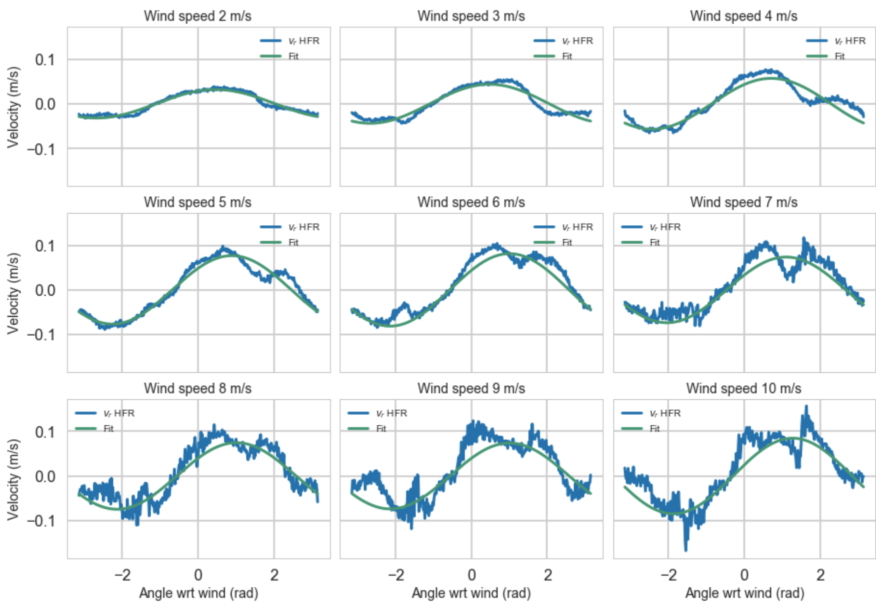
Neutral Winds/Wind Stress

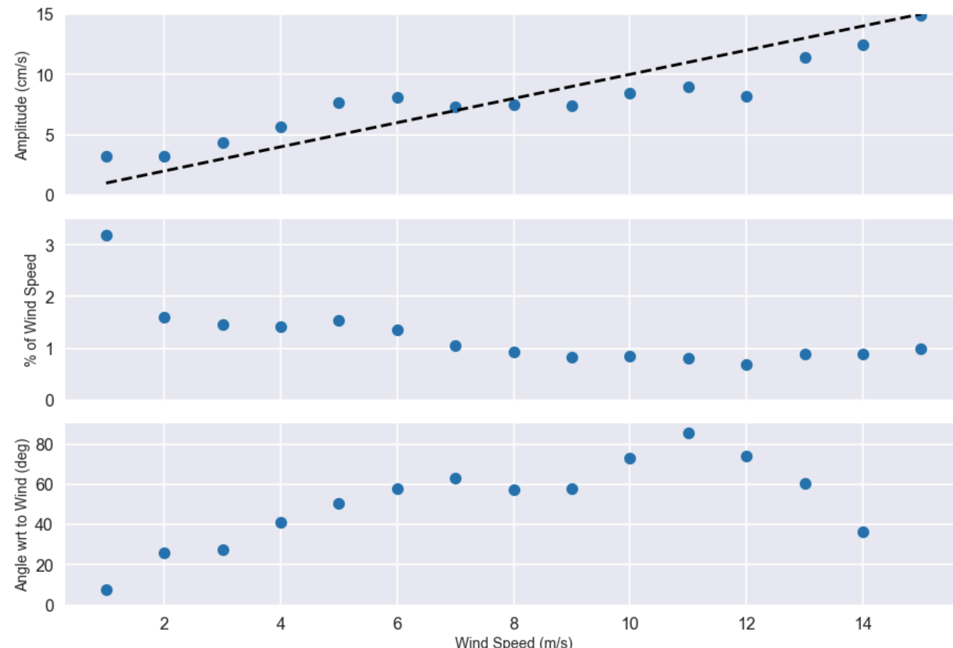


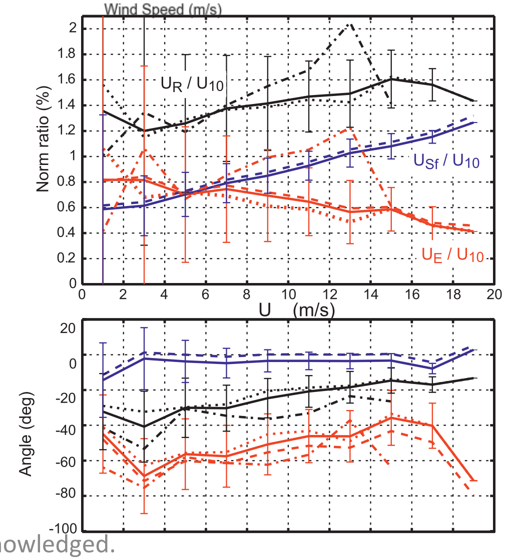
Empirical Wave Component Removal



Near Surface Current Shear





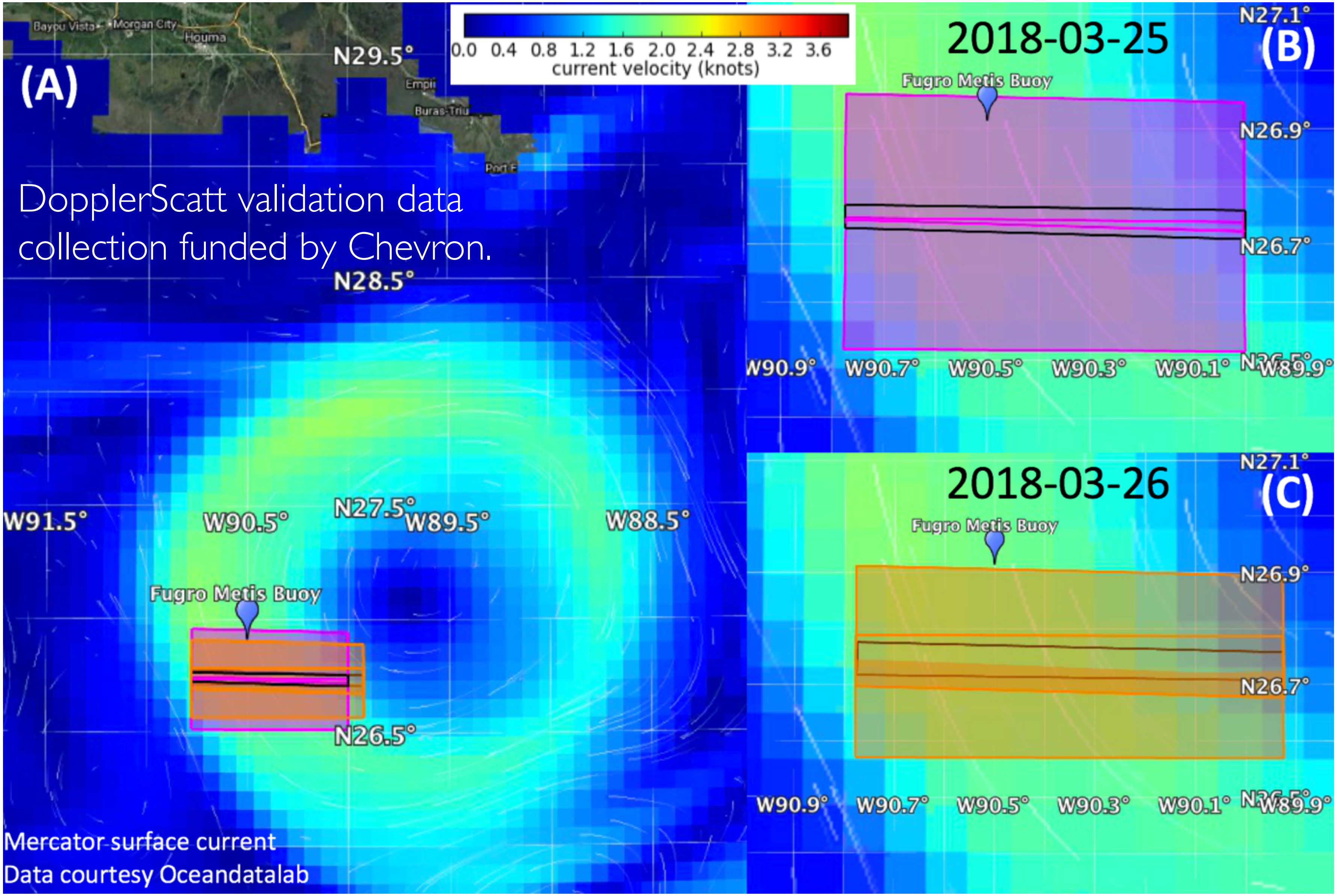


Observation and Estimation of Lagrangian, Stokes, and Eulerian Currents Induced by Wind and Waves at the Sea Surface

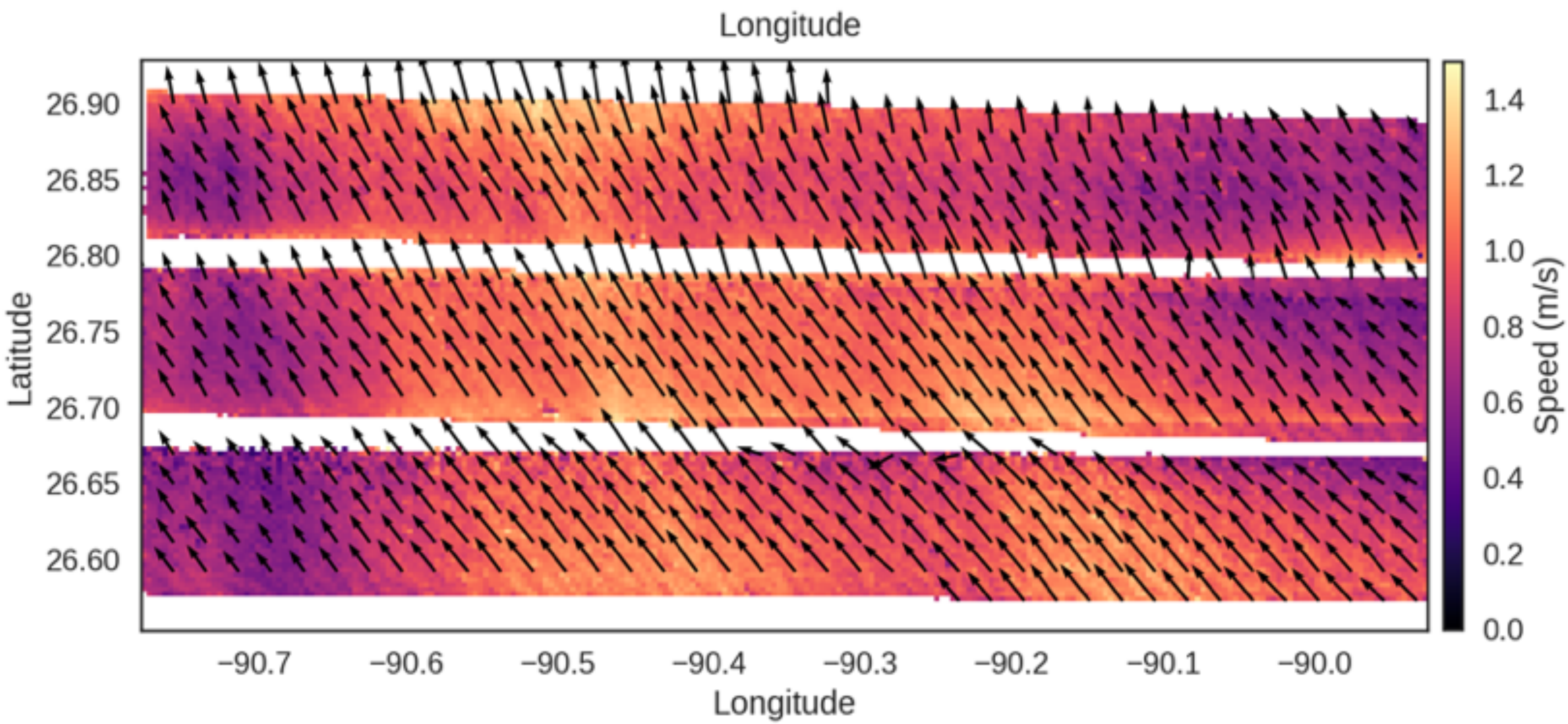
FABRICE ARDHUIN

Service Hydrographique et Océanographique de la Marine, Brest, France

Quantum Eddy Validation



Quantum Eddy Synoptic Currents



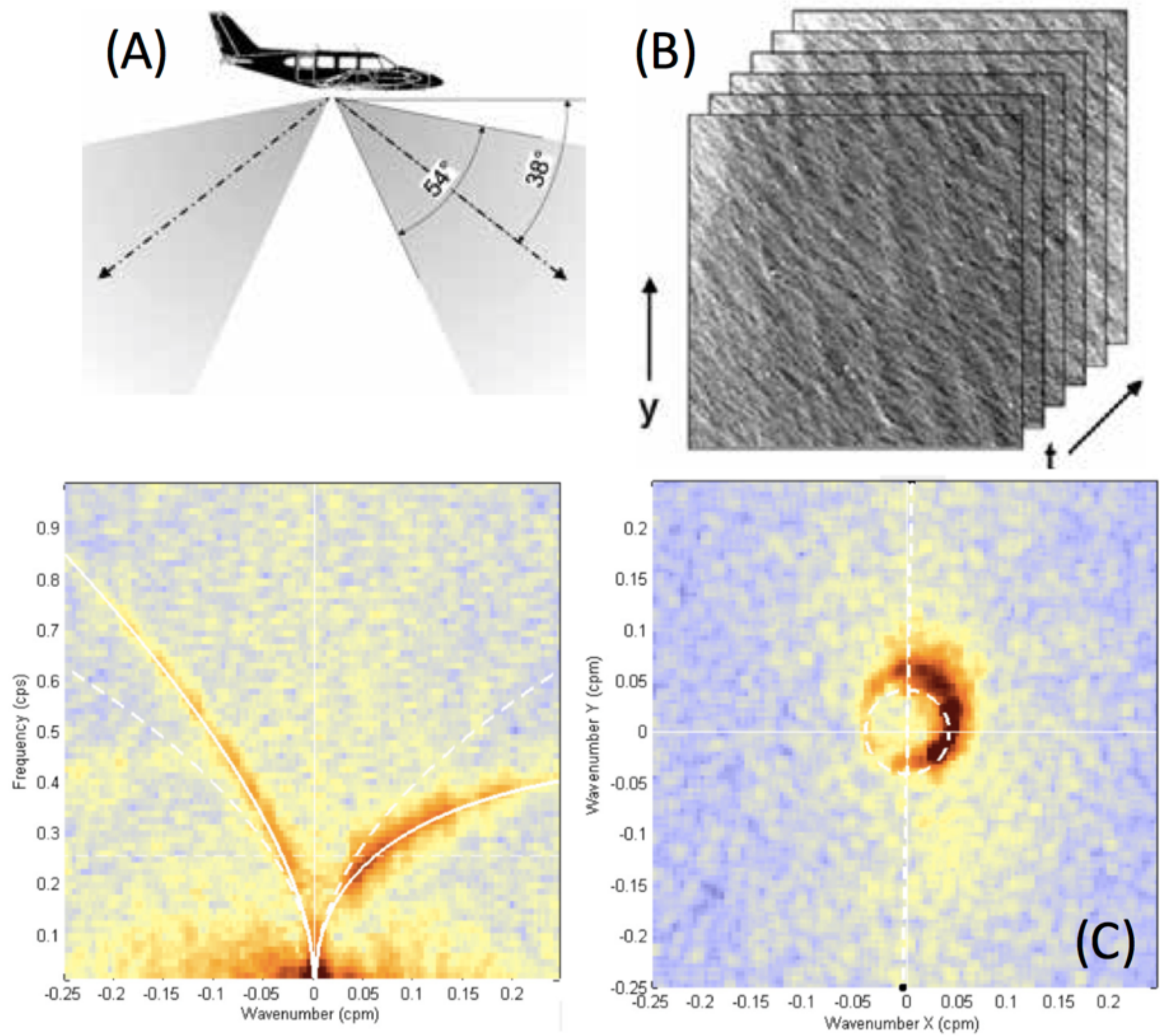
DopplerScatt validation data collection funded by Chevron.

REMOTE OCEAN CURRENT IMAGING SYSTEM (ROCIS)

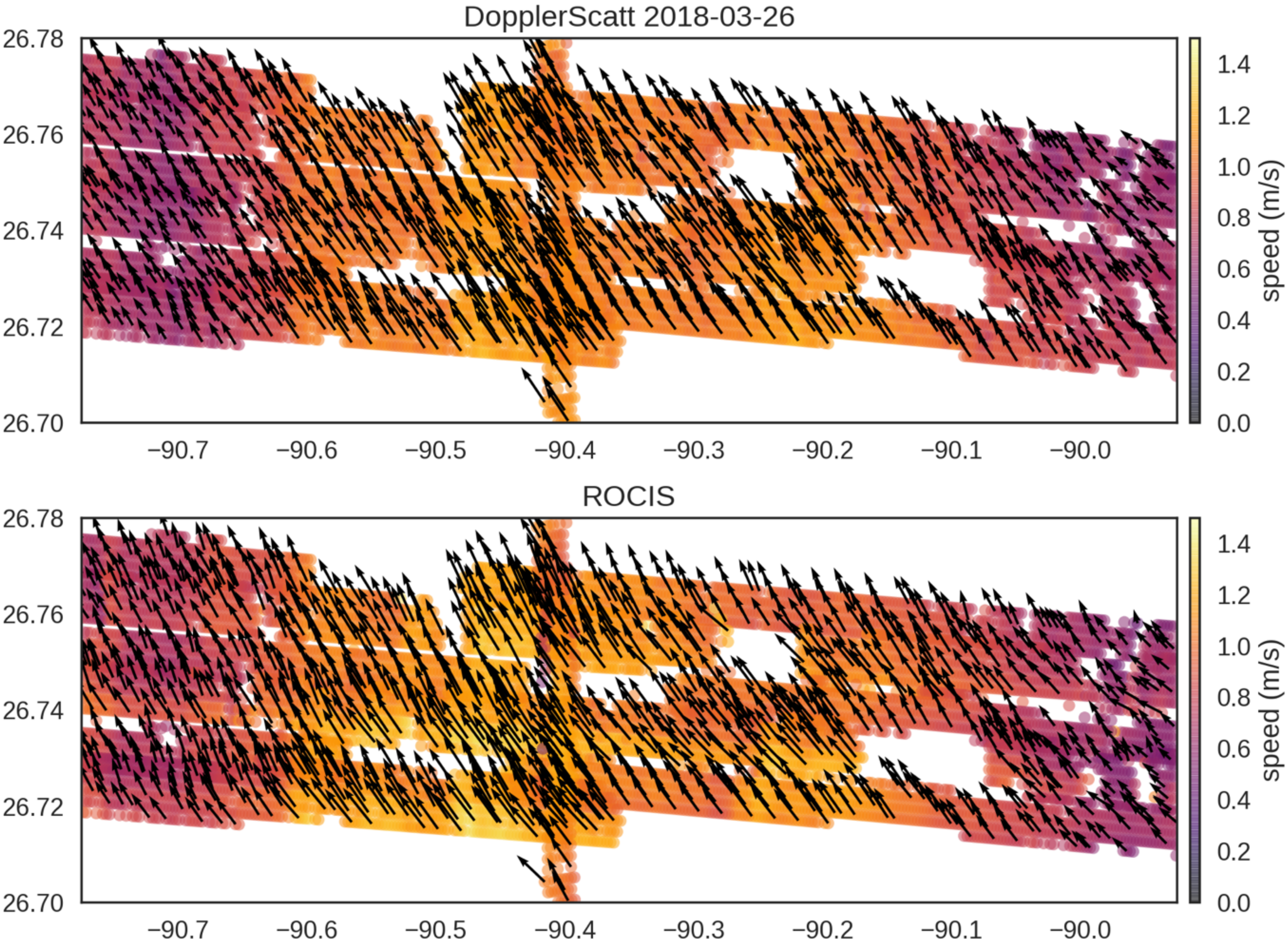
ROCIS - the Remote Ocean Current Imaging System- is an aerial survey payload developed by Fugro and Areté Associates to measure surface ocean currents.

ROCIS validation data collection funded by Chevron.

Uses current induced shifts in the gravity wave dispersion relation to estimate surface currents.

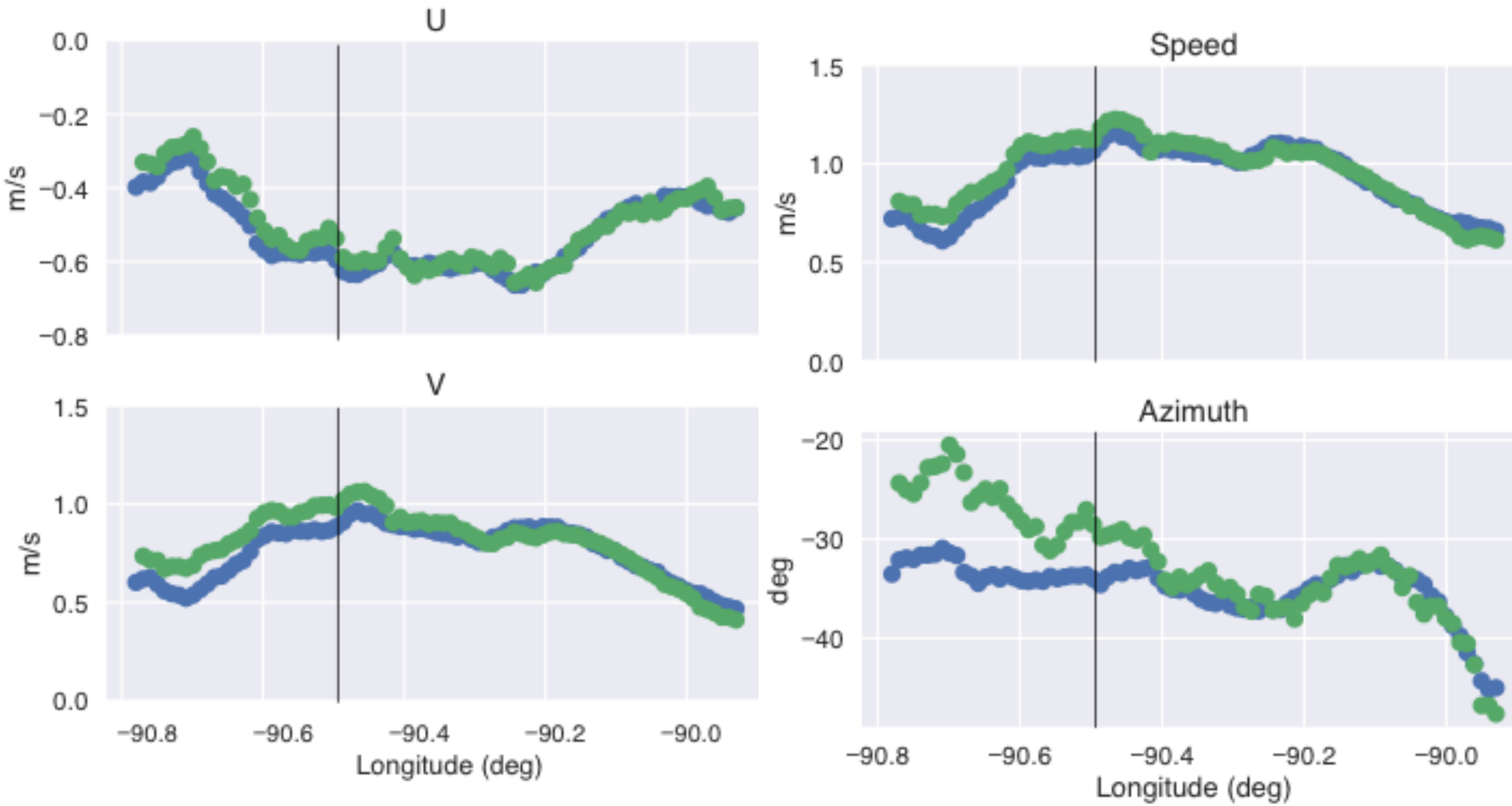


Anderson, S., Zuckerman, S., Smirren, J., and Smith, R. (2015). Airborne ocean surface current measurements for offshore applications. In Offshore Technology Conference Proceedings.

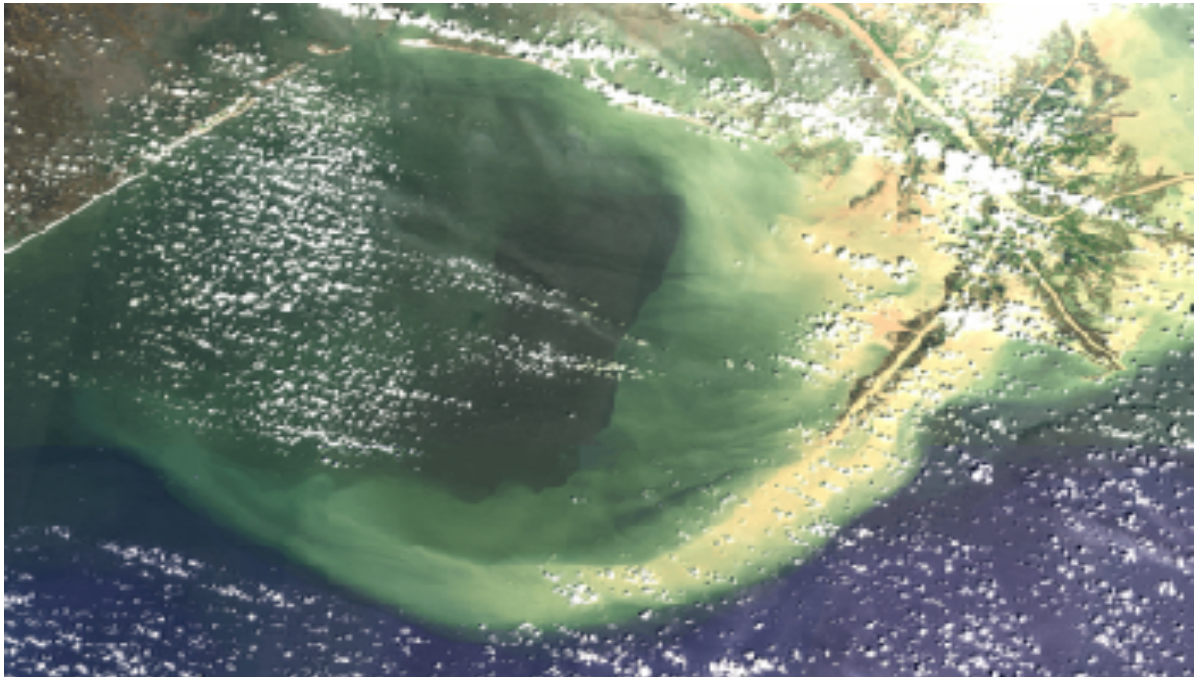


Data collection funded by Chevron. ROCIS data courtesy of Areté Associates.

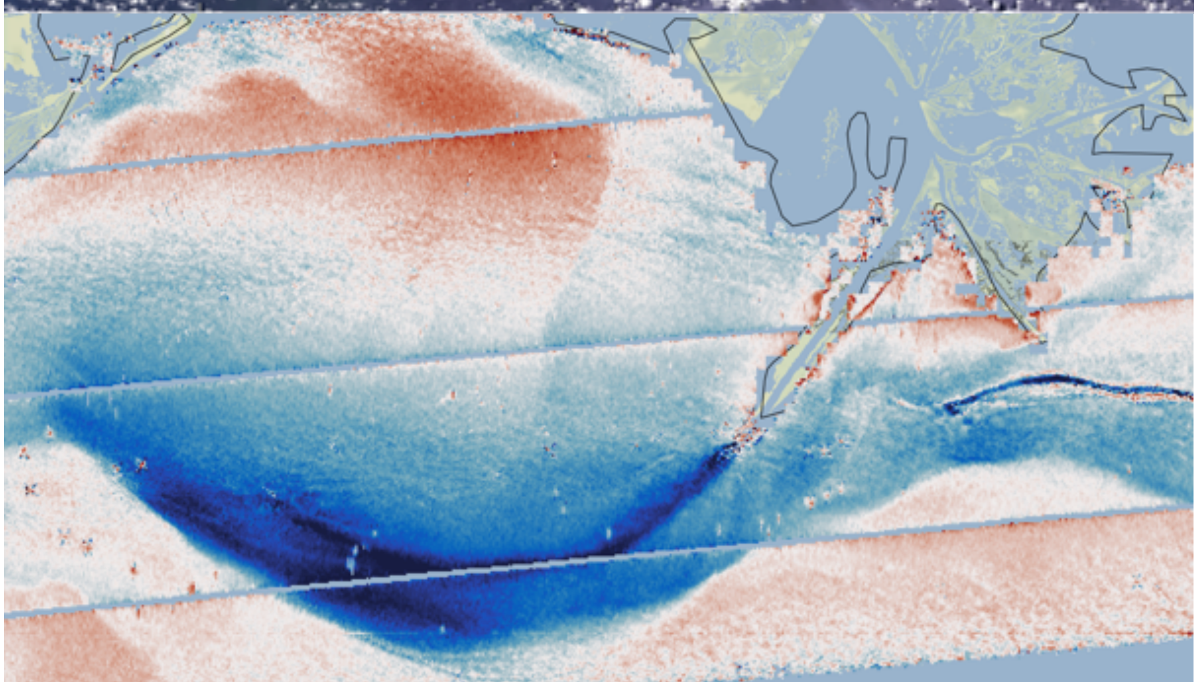
DopplerScatt – ROCIS Comparison



Data collection funded by Chevron. ROCIS data courtesy of Areté Associates.



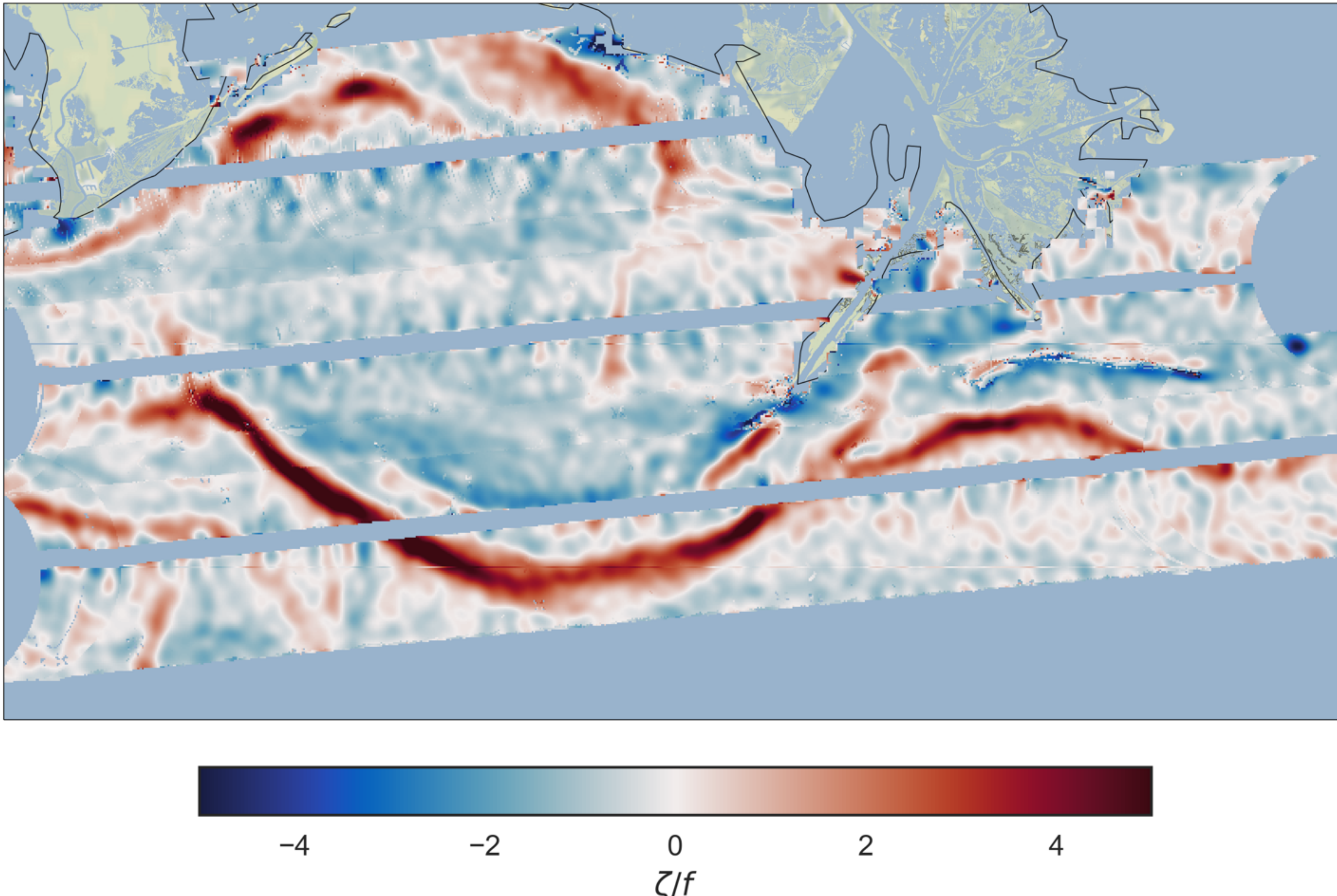
Sentinel 3 2017-04-18
Courtesy of Copernicus
Sentinel, processed by ESA



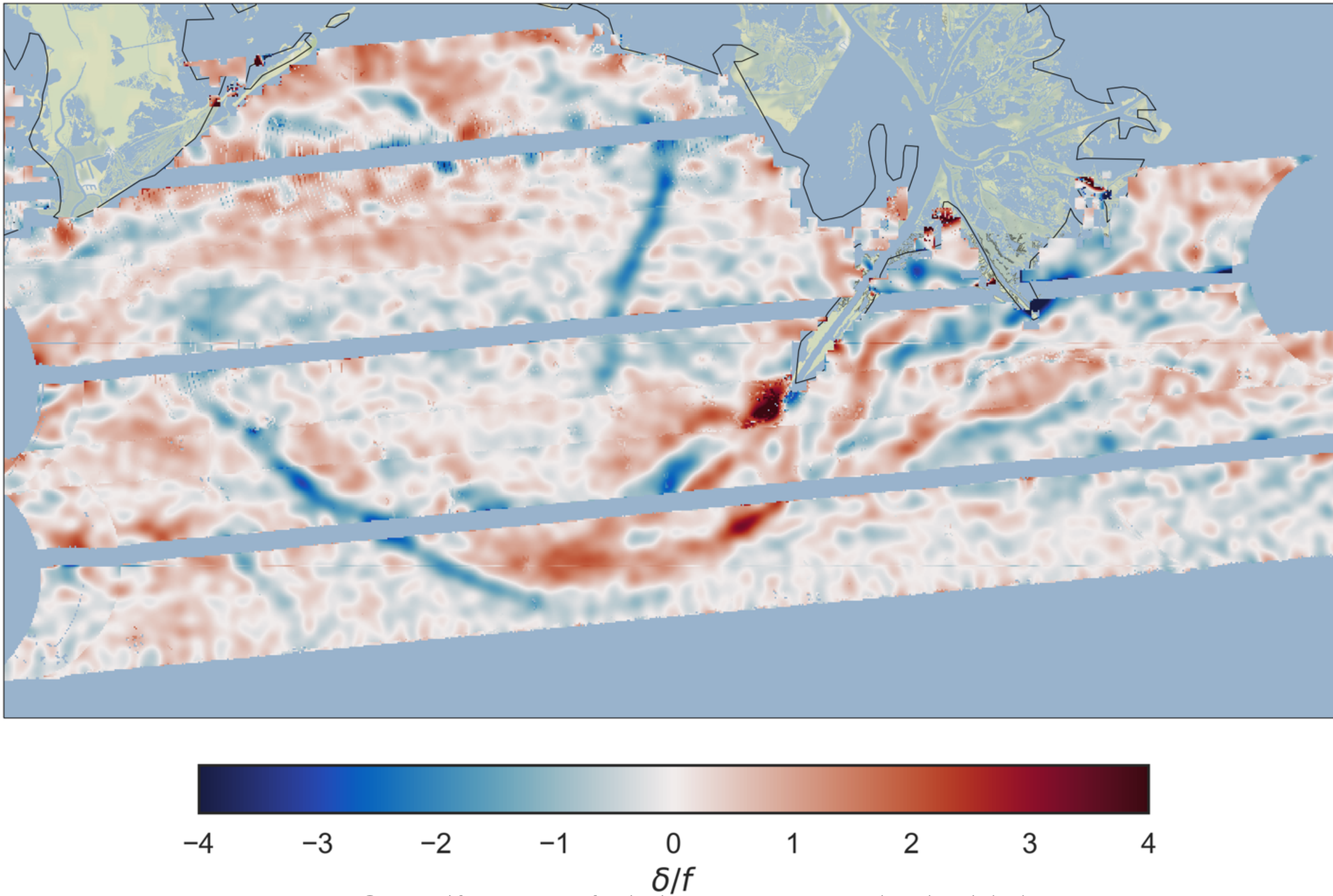
DopplerScatt surface current
U component.

Circulation pattern matches
Sentinel 3 color pattern very
closely.

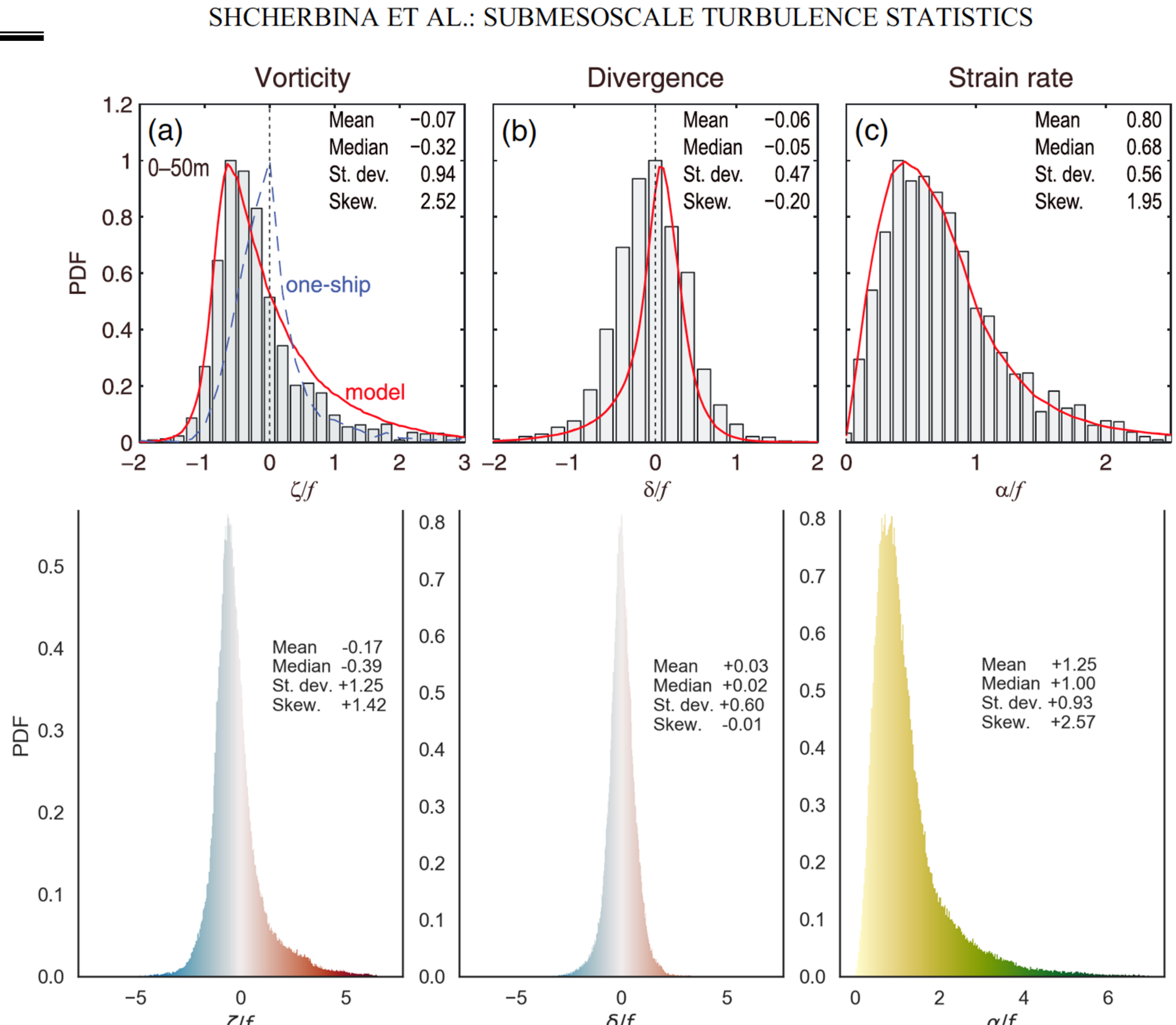
Relative Vorticity



Divergence



Submesoscale Statistics



Skewness > 0 expected as ζ>0 structures have greater stability

Divergence range smaller than vorticity. Slightly skewed towards convergence.

Strain rate approximately chi-squared distributed.

Current Impact on Stress Derivatives

$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_a - \mathbf{U}_o\right| \left(\mathbf{U}_a - \mathbf{U}_o\right)$$

Following Renault et al. (2016, 2017, 2018)

$$\boldsymbol{\tau} \approx \boldsymbol{\tau}_a + \boldsymbol{\tau}_o$$

$$\boldsymbol{\tau}' \approx -\rho C_D \left|\mathbf{U}_a\right| \mathbf{U}_o$$

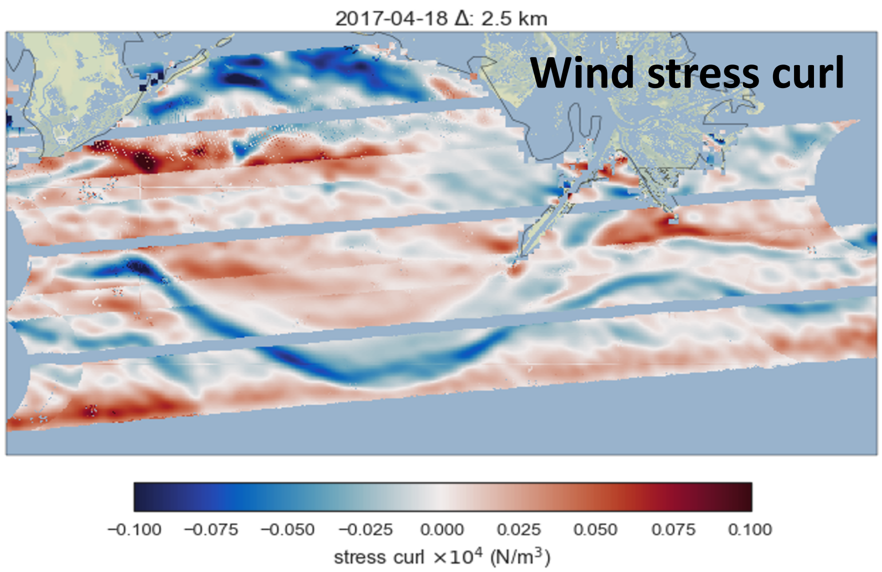
$$\boldsymbol{\tau}_a \approx \rho C_D \left|\mathbf{U}_a\right| \mathbf{U}_a$$

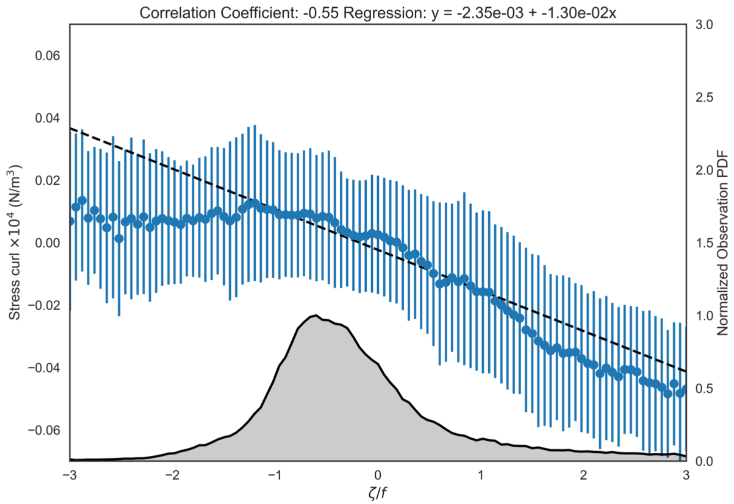
Small scale ocean features dominate the derivatives.

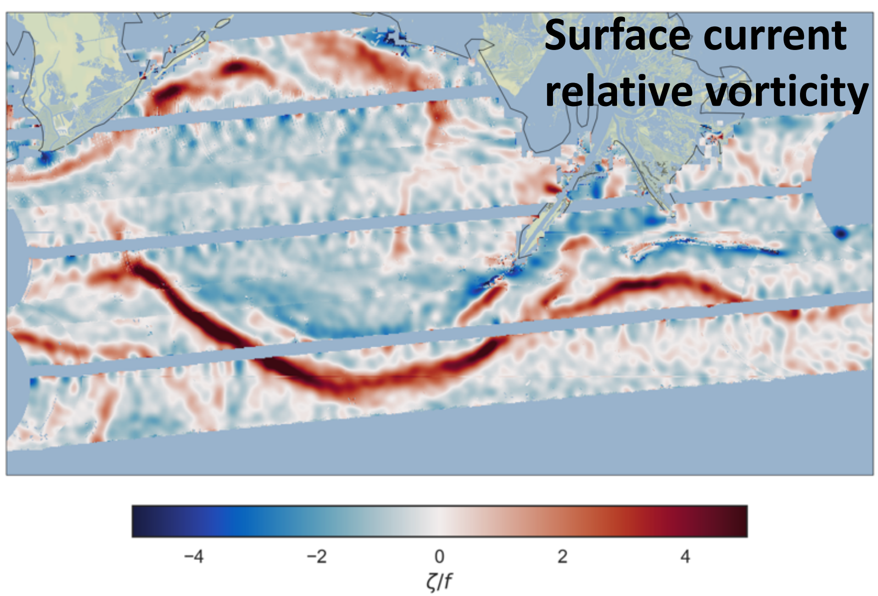
$$\nabla \times \boldsymbol{\tau} \approx \nabla \times \left(\boldsymbol{\tau}_a + \boldsymbol{\tau}_o\right) \approx -\rho C_D \left|\mathbf{U}_a\right| \nabla \times \mathbf{U}_o$$

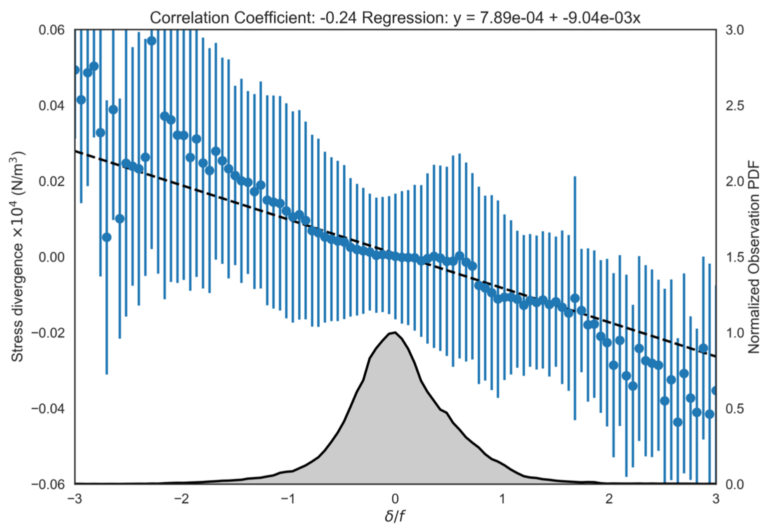
$$\nabla \cdot \boldsymbol{\tau} \approx \nabla \cdot \left(\boldsymbol{\tau}_a + \boldsymbol{\tau}_o\right) \approx -\rho C_D \left|\mathbf{U}_a\right| \nabla \cdot \mathbf{U}_o$$

Current Modulation of Air-Sea Interaction



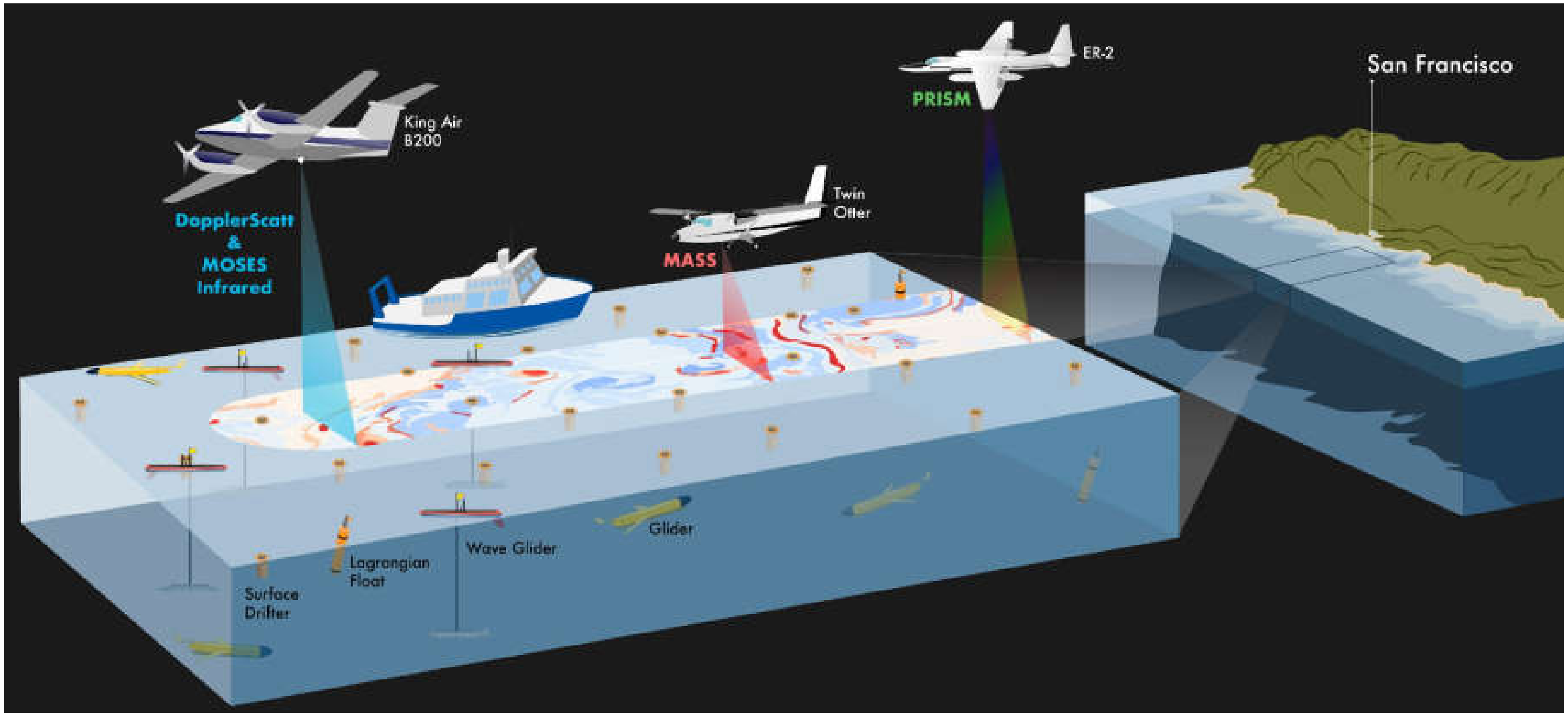






y. Government sponsorship acknowledged.

Coming up



- SMODE: Sub-Mesoscale Ocean Dynamics Experiment
- NASA Earth Ventures Suborbital-3: 2019-2023
- PI Tom Farrar (WHOI)

Summary

- Doppler scatterometry provides a method for measuring vector surface currents and winds.
- Validation results to date show good agreement between DopplerScatt measurements and other measurements, although some differences remain.
- DopplerScatt measurements of sub-mesoscale circulation provide synoptic characterization of the statistics for velocity derivatives, which has been hard until now.
- The ability to measure winds and currents simultaneously opens up a new door into studying air-sea interactions.
- Future data collections through SMODE will provide a unique opportunity to study submesoscale processes.
- Longer-term, there is a potential for a spaceborne system through the Winds and Currents Mission concept (WaCM).